Section 1001
ENGINEERING ECONOMICS

There are four concepts that form the basis of life cycle analysis methodology.

(1) Time value of money.

(2) Opportunity cost of capital.

(3) Discount rate.

(4) Analysis period.

1001.01 Time value of money

Two factors attribute to the time value of money, rate of return and inflation.

1. Rate of Return
2. Inflation

1001.01.1 Rate of Return

The rate of return is the amount of money earned from the use of capital. Interest on a savings account illustrates the rate of return. The rate is calculated for a specific investment. The complexity of the determination varies depending on the length of time considered for the investment.

1001.01.2 Inflation

Inflation is a general increase in the level of prices throughout the economy. A present dollar's purchasing power or worth is greater than a future dollar. Rates are not easily obtainable in that neither accurate or universally acceptable predicting procedures for points far in the future exist. Because analysis considers projects with lives up to 50 years, the use of unreliable inflation rates could lead to inaccurate results.

Inflation affects different segments of the economy in varying ways. For example, inflation in the construction industry may be different from general consumer goods. This makes it difficult to select an appropriate rate for the alternatives being considered.

A diversity of opinions exists on the handling of inflation in LCC analysis. The manner significantly effects the outcome of the analysis. Two types of price changes exist, inflation and differential price trends. During an inflationary period, general increases in prices occur throughout the economy. The difference between the price change for each item being evaluated and the overall economic price trend is differenstial pricing.[7]

A choice between "constant" and "current" dollars must be made during economic analysis. Uninflated constant dollars represent price levels prevailing during the base year. Inflated current dollars represent possible future price levels projected for the costs at a future date. Highway agencies do not normally include inflation when analyzing alternatives because of the uncertainty in predicting future inflation rates. Because only differential inflation on future costs requires identification, the constant dollar method is usually chosen.[7]

1001.02 Opportunity cost of capital

Opportunity cost, the foregone opportunity for an expected rate of return on capital when that capital serves another purposes. In other words, if a funded highway project was postponed to invest the funds, the lost potential return represents the opportunity cost.

1001.03 Discount rate

Use the discount rate as a means to compare alternative uses of funds by reducing the future expected costs or benefits to present day terms. Discount rates reduce costs or benefits to their present worth or annualized costs. The economics of the alternatives can then be compared. The term *interest rate,* associated with borrowing money, is often called the *market interest rate*. The later includes an allowance for expected inflation and a return that represents the real cost of capital.[7]

Why use a discount rate? Because, the value of money is worth more today than a later date; greater purchasing power.

Interest and inflation tend to reduce the future value of a fixed amount of money. For example, rehabilitating a pavement in several years will cost more because of inflation. Proper evaluation first requires the determination of the future cost based on the inflation rate. Using the interest rate, the present worth can be determined. One recommendation, a good approximation, shows the discount rate equal to the interest rate minus the inflation rate. Others suggest that the market interest rate minus inflation in terms of constant dollars be used to estimate the discount rate. Several scholars have suggested a discount rate of 4 percent based on evaluation of historical data.[7]

On a national basis, no consistent agreement exists on a single discount factor for use on public works projects. A survey[7] in 1984 of DOT's in 45 states, the District of Columbia, and three Canadian provinces indicated a rate of four to ten percent for use in LCC analysis. The U.S. Department of Energy, Corps of Engineers, and the Office of Management and Budget use rates of seven, eight, and ten percent, respectively. Respondees using rates at the lower end to the range appear to represent a minority. Using low discount rates is inconsistent with the concepts of opportunity costs and reasonable social discount rates, that rate used for public works projects.

Some even argue that because a high-way agency does not invest funds, an appropriate rate should be <u>zero</u> percent. Two major flaws exist in this thinking. The option disregards the opportunity cost of capital. In addition, it is inconsistent with the concept of the time value of money.

AASHTO's Red Book states "if future benefits and costs are in constant dollars, only the real cost of capital should be represented in the discount rate used. The real cost of capital has been estimated at about 4 percent in recent years for low risk investments." The Portland Cement Association suggests typical values are in the range of 1 and 2.5 percent based on three or four decades of data.[7]

Selection of a low discount rate tends to place greater emphasis on cash flows occurring later in a project's life. The discount rate can significantly effect the outcome of the analysis. The lower the discount rate the greater the effect future dollars have on the present. Therefore, the selection of a low discount rate gives greater emphasis to capital outlays in future years. Erroneous conclusions can result based on an analysis using an inappropriate discount rate.

An equation (follows)[1] to determine the "true interest rate" or real discount rate takes into consideration interest rate, inflation rate, and the rate of increase in highway funding.

$$i^* = \{[(1 + i)(1 + q)]/(1 + f)\} - 1$$

where i^* = True interest rate (discount rate) taking into account the effects of inflation.
i = Interest rate (market).
q = Annual compound rate of increase in highway funding.
f = Annual compound rate of increase in cost of highway construction or maintenance (inflation rate).

Another possibility for a discount rate comes from Eugene Grant and Grant Ireson.[2] They recommend a discount rate of seven percent for highway economy studies. Their rate represents a reasonable opportunity cost and social discount rate.

UDOT (Value Engineering Section) reevaluates the discount rate on a yearly basis and publishes the rate through the Standards Committee. Contact the Value Engineering Section for the current rate.

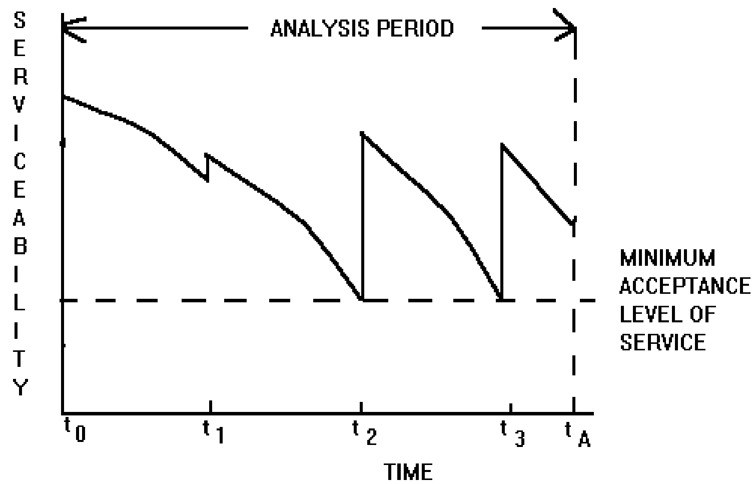
Given the volatility of the issue and the possibility that a single discount rate may change over the years, it is recommended that a sensitivity analysis be done on all analyses using discount rates between four and ten percent, inclusive.

A final thought on the discount rate.

"The discount rate can affect the outcome of a life cycle cost analysis in that certain alternatives may be favored by higher or lower discount rates. High discount rates favor alternatives that stretch out costs over a period of time, since the future costs are discounted in relation to the initial cost. A low discount rate favors *high initial cost alternatives* since future costs are added in at almost face value. In the case of a discount rate equal to 0, all costs are treated equally regardless of when they occur. Where alternative strategies have similar maintenance, rehabilitation, and operating costs, the discount rate will have a minor effect on the analysis and initial costs will have a larger effect."[3]

1001.04 Analysis period[7]

The final component that should be established before performing an LCC analysis is to select an appropriate time period for comparing design alternatives. The analysis period is the total length of time the facility is expected to serve its intended function or the time frame before the component in question requires replacement or upgrade. This period may contain several maintenance and rehabilitation activities. Figure 1 illustrates an example of these activities for pavement performance.



Performance Curve

Determination of the analysis period for highway facilities may be subjective and may not equal the actual physical life. The recommended analysis period for new pavements is 25 to 40 years and 5 to 15 years for rehabilitation alternatives. However, factors such as geometrics, traffic capacity, etc. may dictate a shorter period.

1001.05 Discounted Cash Flow Analysis

Three methods that fit under the major grouping of discounted cash flow analysis are:
1. Annualized Method
2. Present Worth Method
3. Rate-of-Return Method

The first two, annualized and present worth, have been the primary economic methods used in life-cycle costing analyses. The rate of return method requires more effort and calculations to perform. Therefore, this method does not have general support. The two primary methods are discussed below:

1001.05.1 Annualized Method

One of the most valuable tools of economic analysis, this method converts present and future expenditures to a uniform annual cost, resulting in a common base of a uniform annual cost. Quality equates to accuracy. Divide expected costs, positive or negative, over the life of the system into uniform annual costs using the appropriate discount rate.

This method converts initial, recurring, and nonrecurring costs into annual payments. Estimated uniform annual maintenance expenditures are recurring costs already in terms of annual cost. Future expenditures must be converted to present worth using the above equation before using the following equation to determine annualized cost.[7]

$$A = P\{[i(1 + i)^n]/[(1 + i)^n - 1]\}$$

where

P	=	Present worth
A	=	Annualized cost or annual cost
n	=	Number of years
i	=	Discount rate

The factor $[i(1 + i)^n]/[(1 + i)^n - 1]$ is also know as the Uniform Capital Recovery Factor (UCR).

or

(A/P,i%,n)

A simplified calculation for A involves multiplying P by the UCR, found in standard economic tables.

The advantage of the latter method is that it can be utilized to calculate the annual cost of alternatives with different lives.

As mentioned previously, the various cash flow factors have been calculated and tabulated. The factors are available in most engineering economics texts.

8-1001.05.2 Present Worth Method

The present worth method is an economic method that involves the conversion of all of the present and future expenses to a base of today's costs. The present worth of some planned future expenditure is equivalent to the amount of money that would need to be invested now at a given compound interest rate for the original investment plus interest to equal the expected cost at the time it is needed.[7]

Factor Name	Converts	Symbol	Formula
Single payment compound interest	P to F	(F/P,i%,n)	$(1 + i)^n$
Present Worth	F to P	(P/F,i%,n)	$1/(1 + i)^n$
Uniform series Sinking Fund	F to A	(A/F,i%,n)	$i/[(1 + i)^n - 1]$
Capital Recovery	P to A	(A/P,i%,n)	$[i(1 + i)^n]/[(1 + i)^n - 1]$

Table 1 Discount Factors for Discrete Compounding

This allows the comparison of alternatives having outlays at different points in their lives on an equal basis. A disadvantage in the use of the present worth method is that the method can only be used to compare alternatives with equal analysis periods. The present worth method cannot be used, for example, to compare alternatives with lives of 20 and 50 years.

The following formulas are presented to facilitate understanding of the derivation of the various factors used in life cycle analyses. In most cases actual manual calculations are not necessary because these factors have been calculated and tabulated for various interest rates. Examples illustrate the use of the these tables. Table 1 lists the discount factors used in these tables.[4]

The general form of the present worth equation for a single present worth of a future sum follows:

$$P = F[1/(1 + i)^n]$$

where P = Present worth
F = The future sum of money at the end of n years
n = Number of years
i = Discount rate

The factor $1/(1 + i)^n$ is also known as the Single Payment Present Worth (SPW).

or

(P/F,i%,n)

A simplified calculation for P involves multiplying F by the SPW or factor.

Use the following equation for present worth of a series of end-of-year payments.

$$P = A\{[(1 + i)^n - 1]/[i(1 + i)^n]\}$$

where A = End-of-year payments in a uniform series for n years that is equivalent to P at discount rate i.

The factor $[(1 + i)^n - 1]/[i(1 + i)^n]$ is also known as the Uniform Present Worth Factor (UPW).

or

(P/A,i%,n)

A simplified calculation for P involves multiplying A by the UPW or factor.

Examples

See Appendix A for examples of Discounted Cash Flow.

1001.06 Sensitivity Analysis

Cost and benefit variables, including discount rates, analysis period, and the costs of various factors including maintenance and user costs related to specific projects have varying effects. Sensitivity is the relative effect that each variable may have on the choice of alternatives. Sensitivity analysis tests the effects of variations in these variables. Testing identifies the most influential variables and the extent of influence. The analysis may identify design options requiring further consideration in greater detail and variables requiring additional information. Project risk may also be identified. Sensitivity analysis takes place as part of an economic analysis, in the formative stages of a project.

Inadequate input data, initial assumptions, accuracy of estimates, or any combination effects the outcome. The following critical questions must be answered.

1. How sensitive are the results of the analysis to variations in these uncertain parameters?

2. Will these variations tend to justify the selection of an alternative not currently being considered.

3. How much variation in a given parameter is required to shift the decision to select alternative B rather than alternative A?"[5]

Sensitivity analysis has two purposes, to determine how sensitive the outputs from the life cycle cost analysis are to variations in certain inputs and to evaluate the risk and uncertainty related to a selected alternative. The designer can then determine the probability of making the wrong choice or selecting the wrong alternative. The analysis provides the greatest benefit when the difference between alternatives may not be very great. Accomplish the analysis when performing a more detailed life cycle cost analysis.

While this process is not difficult or time consuming, the entire LCC analysis process contains a great deal of uncertainty. The means to determine the effect of this uncertainty on numerous factors is found in sensitivity analysis. Results of analyses related to other agencies shows that:

- "Results of solutions by the annual cost method are markedly affected by interest rate. Low interest rates favor those alternatives that combine large capital investments with low maintenance or user costs, whereas high interest rates favor reverse combinations."[3]

- "As the interest rates increase and the time period grows longer, then the assumption that a system will be used for an indefinite period of time becomes less significant. Forecasts into the future are less significant when interest rates are higher and the periods of time are longer than are short range forecasts using lower interest rates."[5]

- "It was found that if the resurfacing costs and/or reconstruction costs increased slightly, then with a 10% discount rate, the road would be resurfaced one more time before reconstruction. Similarly, if these costs decreased slightly and a 5% discount rate is used, the pavement would be resurfaced one fewer times before reconstruction."[6]

1. Cady, P.D., "Inflation and Highway Economic Analysis," *ASCE Journal of Transportation Engineering*, Vol. 109, No. 5, Paper No. 18248, 1983.

2. Grant, Eugene L., W. Grant Ireson, and Richard S. Leavenworth, "Principles of Engineering Economy," Wiley, 1982.

3. Kleskovic, Peter Z., "A Discussion of Discount Rates for Economic Analysis of Pavements," Draft Report, FHWA Pavement Division, February 1990.

4. Lindeburg, Michael R., P.E., *Civil Engineering Reference Manual, 5th Edition*, "Engineering Economic Analysis," Professional Publications, California, 1989.

5. Keely, B.J. and J.W. Griffith, "Life Cycle Cost-Benefit Analysis: A Basic Course in Economic Decision Making," Report N. HEW/OFEPM-75/06, Department of Health, Education, and Welfare, Washington, D.C., 1975.

6. McNeil, S. and C. Hendrickson, *Three Statistical Models of Pavement Management Based on Turnpike Data with an Application to Roadway Cost Allocation*, Federal Highway Administration, Department of Transportation, Washington, D.C., 1981.